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(54) **Method of forming crystalline silicon carbide coatings.**

(57) A method of forming crystalline silicon carbide films is disclosed. The method comprises a chemical vapor deposition process in which a substrate is heated to a temperature above 600°C. in the presence of trimethylsilane gas.

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The present invention relates to the growth of crystalline silicon carbide films at low temperatures using trimethylsilane as the source gas in a chemical vapor deposition (CVD) process.

Crystalline silicon carbide is useful in many high temperature, high power and high frequency semiconductor device applications because of properties such as a wide bandgap, high saturated electron drift velocity, high breakdown electric field, high thermal conductivity, and good chemical resistance. However, most fabrication processes require the formation of single crystal silicon carbide films. Normally, these films are grown by CVD at temperatures above 1000°C. For instance, Learn et al., Appl. Phys. Lett., Vol. 17, No. 1, July 1970, teach the formation of cubic silicon carbide on alpha (6H) and beta (3C) silicon carbide substrates by the reactive evaporation or reactive sputtering of silicon in acetylene at temperatures as low as 1100°C. Similarly, Stecki and Li, IEEE Transactions on Electronic Devices, Vol. 39, No. 1, Jan. 1992, describe the formation of beta (3C) silicon carbide films on carbonized silicon (100) by rapid thermal CVD of silane and propane at 1100-1300°C.

Other investigators have also demonstrated the deposition of 3C silicon carbide films from organosilicon precursors. For instance, Takahashi et al., J. Electrochem. Soc., Vol 139, No. 12, Dec. 1992, disclose the formation of 3C silicon carbide on Si(100) and Si(111) substrates (with and without a carbonized layer) by atmospheric pressure CVD using hexamethyldisilane and hydrogen gas mixtures at temperatures of 1100°C.

Golecki et al., Appl. Phys. Lett, 60 (14), April 1992, reveal the formation of cubic silicon carbide on silicon (100) substrates by low pressure CVD using methylsilane at substrate temperatures as low as 750°C. The process described therein, however, is solely limited to the use of methylsilane as the precursor gas.

The use of trimethylsilane to form amorphous or polycrystalline silicon carbide films is also known in the art. For instance, Kaplan et al. in U.S. Patent No. 3,843,399 teach the formation of silicon carbide coatings on video disks using trimethylsilane in a glow discharge CVD process. Similarly, Japanese Kokai Patent Publication 52-14600 forms silicon carbide films on a variety of substrates using an alkylsilane in a glow discharge chemical vapor deposition process. Likewise, Edno et al. in U.S. Patent No. 4,532,150 details the formation of silicon carbide coatings using an organosilicon compound in a plasma enhanced CVD process. Neither of these references, however, suggest the formation of crystalline silicon carbide.

The present invention describes the deposition of crystalline silicon carbide films using trimethylsilane in a CVD process.

The present invention provides a method of forming a crystalline silicon carbide film on a substrate.

The method comprises heating the substrate to a temperature above 600°C. and exposing the heated substrate to trimethylsilane gas to thereby deposit a crystalline silicon carbide film. Optionally, a thin silicon carbide layer can be grown on the substrate by reacting it with a hydrocarbon gas ("carbonization") prior to deposition of the crystalline silicon carbide film.

The present invention allows the deposition of crystalline silicon carbide (SiC) films at temperatures as low as 600 and up to 1000°C. using trimethylsilane gas.

Nearly any desired substrate can be used in the process of the present invention. Generally, however, it is preferred to use a substrate comprising either single crystal silicon carbide or a single crystal silicon wafer. Such substrates are commercially available. The first step in our process is, generally, cleaning the desired substrate. This cleaning provides a pristine crystalline surface to insure epitaxial growth. Obviously, however, if such a surface is available the additional cleaning is not necessary. Nearly any method which provides the desired clean surface can be used and many of these methods are known in the art. For instance, the substrate can be etched by dipping in an acid such as HF. Alternatively, the substrate can be etched in a corrosive atmosphere such as HCl/H₂ at elevated temperatures (1000°C. or above).

If a silicon substrate is used, a thin buffer layer of silicon carbide can be grown on the cleaned surface. Again, processes for growing these layers are known in the art and nearly any which can provide the desired silicon carbide layer can be used. One example of such a process involves exposing the silicon to a hydrocarbon gas ("carbonization") at elevated temperatures under atmospheric or low pressure conditions. Hydrocarbons such as methane, ethane, propane, butane, ethylene and acetylene may be used. Specific examples of such processes include directing a stream of gas comprising propane diluted in H₂ (at a flow rate of 9 sccm) and H₂ (at a flow rate of 0.9 l/min) at the substrate under atmospheric pressure at 1300°C. to produce a 25 nanometer SiC layer in 1 minute. Another example of such a process includes directing a stream of gas comprising propane (at a flow rate of 99 sccm) and H₂ (at a flow rate of 0.9 l/min) at the substrate under 0.67 kPa (5 Torr) at 1300°C. to produce a 120 nanometer SiC layer in 1 minute. If a silicon carbide substrate is used, it is not necessary to form the above layer.

The crystalline silicon carbide layers are then formed on the substrates by a standard CVD process in which the substrate is heated to the desired temperature in a deposition chamber followed by exposing the substrate to trimethylsilane. Substrate temperatures above 600°C. are useful herein with temperatures in the range of 600 to 1200°C. being preferred. More preferred are temperatures in the range

of 600 to 1000°C.

The time necessary for the formation of the films varies depending on the concentration of trimethylsilane in the growth chamber and the desired film thickness. Generally, exposure times of 1-30 minutes are sufficient.

The silicon carbide precursor used in the process of the present invention is trimethylsilane, $(\text{CH}_3)_3\text{SiH}$. This gas and methods for its production are known in the art. For example, trimethylsilane can be produced by introducing methyl groups into trichlorosilane by the Grignard process. Alternatively, the trimethylsilane can be produced by reacting trimethylchlorosilane with a metal hydride. These and other methods are described by Noll in "Chemistry and Technology of Silicones", New York, Academic Press 1968, p. 87 ff.

The trimethylsilane gas is generally diluted in the deposition chamber with an inert carrier gas. Such carriers include hydrogen, argon and helium. Although the dilution is dependent on the rate of exposure to the substrate, generally dilutions of trimethylsilane:carrier in the range of 1:1 to 1:10000 are used.

The total pressure of the gases (trimethylsilane + carrier) in the deposition chamber can be varied over a wide range and is generally controlled to a level which provides a reasonable rate of epitaxial film growth. Generally, pressures in the range of 133.3 μPa (10^{-6} Torr) to atmospheric pressure are used.

The amount of chemical vapor introduced into the deposition chamber should be that which allows for a desirable SiC film growth rate. It is preferred, however, that the deposition chamber be "starved" such that nearly all of the trimethylsilane in the atmosphere is deposited, thereby slowly growing the crystalline structure. Growth rates in the range of 1-1000 nanometers/min may generally be achieved.

The process of the invention can be conducted under static conditions, but it is usually preferred to continuously introduce a controlled amount of vapor into one portion of a chamber while drawing a vacuum from another site in the chamber so as to cause flow of the vapor to be uniform over the area of the substrate.

The deposition chamber used in the process of the invention can be any which facilitates the growth of films by a CVD process. Examples of such chambers are described by Golecki et al. and Steckl et al., supra.

In addition, it is contemplated that the crystalline silicon carbide epitaxial growth can be assisted by a variety of vapor deposition processes. For instance, it is contemplated that techniques such as molecular beam epitaxy, laser assisted CVD, ion beams and hot filaments can be used to decompose the gaseous species and, thereby, grow the epitaxial layer at lower temperatures.

The resultant films are single phase or polycrys-

talline SiC. They can be grown in a wide variety of thicknesses such as from 0.01 to 5 micrometers.

5 Claims

1. A method of growing an epitaxial silicon carbide film on a substrate selected from silicon and silicon carbide comprising:
 - heating the substrate to a temperature in the range of 600°C. to 1000°C.; and
 - exposing the heated substrate to a gas comprising trimethylsilane for a time sufficient to grow the epitaxial silicon carbide film.
2. The method of claim 1 wherein a silicon carbide buffer layer is grown on the silicon substrate by carbonization prior to growing the epitaxial silicon carbide film.
3. The method of claim 1 wherein the substrate is silicon and is cleaned prior to growing a silicon carbide buffer layer by a method selected from dipping the substrate in an acid and exposing the substrate to HCl/H_2 at a temperature above 1000°C.
4. The method of claim 2 wherein the carbonization is performed by exposing the substrate to a gas mixture comprising a hydrocarbon and hydrogen gas at a temperature above 1000°C.
5. The method of claim 4 wherein the hydrocarbon gas is selected from methane, ethane, propane, butane, ethylene and acetylene.
6. The method of claim 1 wherein the gas also comprises an inert carrier gas in a ratio of trimethylsilane:carrier in the range of 1:1 to 1:10000.
7. The method of claim 1 wherein the heated silicon substrate is exposed to the trimethylsilane gas for a time in the range of between 1 and 30 minutes.
8. The method of claim 1 wherein the heated silicon substrate is exposed to the trimethylsilane gas at a pressure in the range of between 133.3 μPa (10^{-6} Torr) and atmospheric pressure.
9. The method of claim 1 wherein growth of the epitaxial silicon carbide film is assisted by a vapor deposition technique selected from molecular beam epitaxy, ion beams, lasers assisted CVD and hot filaments.
10. The method of claim 1 wherein the gas also comprises $(\text{CH}_3)_3\text{SiP}$.



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EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT			EP 94304588.0
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 6)
A	APPLIED PHYSICS LETTERS, vol. 42, no. 5, March 1, 1983 S. NISHINO et al. "Production of large-area single-crystal wafers of cubic SiC for semiconductor devices" pages 460-462 * Page 461, left column, lines 2-24 *	1-10	C 23 C 16/32 C 23 C 16/24
A	APPLIED PHYSICS LETTERS, vol. 44, no. 5, March 1, 1984 A. ADDAMIANO et al. "Buffer-layer" technique for the growth of single crystal SiC on Si" pages 525-527 * Totality *	1-10	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 6)
D, A	APPLIED PHYSICS LETTERS, vol. 60, no. 14, April 6, 1992 I. GOLECKI et al. "Single-crystalline, epi- taxial cubic SiC films grown on (100) Si at 750 degrees C by chemical vapor deposition" pages 1703-1705 * Totality, *	1-10	C 23 C
D, A	J. ELECTROCHEM. SOCIETY, vol. 139, no. 12, December 1992 K. TAKAHASHI et al. "Low-Temperature Growth of 3C-SiC on Si Substrate by	1-10	
The present search report has been drawn up for all claims			
Place of search VIENNA		Date of completion of the search 25-01-1995	Examiner HAUK
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone V : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl. 6)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
D, A	Chemical Vapor Deposition Using Hexamethyldisilane as a Source Material" pages 3565-3571 * Totality * -- PATENT ABSTRACTS OF JAPAN, unexamined applications, C section, vol. 1, no. 54, May 25, 1977 THE PATENT OFFICE JAPANESE GOVERNMENT page 418 C 77; & JP-A-52 014 600 (JUICHIRO OZAWA) --	1-10	TECHNICAL FIELDS SEARCHED (Int. Cl. 6)
A	PATENT ABSTRACTS OF JAPAN, unexamined applications, C field, vol. 12, no. 92, March 25, 1988 THE PATENT OFFICE JAPANESE GOVERNMENT page 65 C 483; & JP-A-62 224 674 (SHARP CORP.) --	1-10	
A	PATENT ABSTRACTS OF JAPAN, unexamined applications, C field, vol. 16, no. 86, March 3, 1992 THE PATENT OFFICE JAPANESE GOVERNMENT page 110 C 916; & JP-A-03 274 273 (TOAGOSEI CHEM. IND. CO. LTD.) --	1-10	
A	US - A - 5 053 255 (HERMAN J. BOEGLIN) * Abstract; claims 1-12 * --	1-10	
The present search report has been drawn up for all claims			
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DOCUMENTS CONSIDERED TO BE RELEVANT			-3- EP 94304588.0
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 6)
A	EP - A - 0 193 998 (N.V. PHILIPS' GLOEILAMPEN- -FABRIEKEN) * Abstract; claims 1-5 *	1-10	
A	WO - A - 88/04 333 (THE BRITISH PETROLEUM COMPANY P.L.C.) * Abstract; claims 1-12 *	1-10	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 6)
The present search report has been drawn up for all claims			
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<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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